

# The problem of the spin of the proton and elastic neutrino-proton scattering\*

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The experiments on the measurement of the deep inelastic scattering of longitudinally polarized leptons on longitudinally polarized nucleons[1, 2, 3] led to an essential progress in the investigation of the structure of the nucleon. The recent experiments done at CERN[2] and at SLAC[3] confirm the conclusion that have been reached after the EMC data[1] became available: the one-nucleon matrix element of the strange axial current is large and it's size is comparable with the matrix elements of the  $u$  and  $d$  axial currents. From the analysis of the latest data it follows that[4]

$$\begin{aligned} g_A^u &= 0.83 \pm 0.03 , \\ g_A^d &= -0.43 \pm 0.03 , \\ g_A^s &= -0.10 \pm 0.03 . \end{aligned} \tag{1}$$

The constants  $g_A^q$  are determined by

$$\langle p | \bar{q} \gamma_\alpha \gamma_5 q | p \rangle = \bar{u}(p) \gamma_\alpha \gamma_5 u(p) g_A^q , \quad q = u, d, s , \tag{2}$$

where  $|p\rangle$  is the state vector of a nucleon with momentum  $p$ . The values (1) of the constants  $g_A^q$  were determined under the assumption of a Regge behaviour of the polarized structure function  $g_1$  at small  $x$ . The SU(3)-based relation between the constants  $g_A^q$  and the constants  $F$  and  $D$  were also used.

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Alternative approaches to the “problem of the spin of the proton” are of great interest. The investigation of the NC-induced processes

$$\nu_\mu + N \rightarrow \nu_\mu + N \quad (3)$$

$$\bar{\nu}_\mu + N \rightarrow \bar{\nu}_\mu + N \quad (4)$$

can become an important model independent source of information about the axial and vector strange form factors [5, 6].

The one-nucleon matrix element of the hadronic neutral current has the following general form:

$$\langle p' | J_\alpha^Z | p \rangle = \bar{u}(p') \left[ \gamma_\alpha F_V^Z(Q^2) + \frac{i}{2M} \sigma_{\alpha\beta} q^\beta F_M^Z(Q^2) + \gamma_\alpha \gamma_5 F_A^Z(Q^2) \right] u(p) . \quad (5)$$

Here  $Q^2 \equiv -q^2$ , where  $q = p' - p$ ,  $p$  and  $p'$  being the momenta of the initial and final protons, respectively. Using the isotopic SU(2) symmetry of the strong interactions, for the vector and axial NC form factors we have

$$F_{V,M}^Z = F_{1,2}^3 - 2 \sin^2 \theta_W F_{1,2}^{p(n)} - \frac{1}{2} F_{V,M}^s , \quad (6)$$

$$F_A^Z = \frac{1}{2} F_A - \frac{1}{2} F_A^s . \quad (7)$$

Here  $F_1^{p(n)}$  and  $F_2^{p(n)}$  are the Dirac and Pauli electromagnetic form factors of the proton,

$$F_{1,2}^3 = \frac{1}{2} (F_{1,2}^p - F_{1,2}^n) \quad (8)$$

are the isovector form factors of the nucleon,  $F_A$  is the CC axial form factor, and  $F_{V,M}^s$  and  $F_A^s$  are the form factors that characterize the one-nucleon matrix elements of the vector  $\bar{s}\gamma_\alpha s$  and axial  $\bar{s}\gamma_\alpha \gamma_5 s$  currents.

It is possible to obtain information about the axial form factor  $F_A$  from the investigation of the quasi-elastic CC processes

$$\nu_\mu + n \rightarrow \mu^- + p , \quad (9)$$

$$\bar{\nu}_\mu + p \rightarrow \mu^+ + n . \quad (10)$$

However, the axial form factor cannot be determined from the existing CC data with an accuracy sufficient to obtain the value of the constant  $g_A^s$  from the NC elastic scattering data[7].

In order to avoid the uncertainties connected with our lack of knowledge of the axial form factor  $F_A$  we have considered[6] the asymmetry[8, 9]

$$\mathcal{A}_N(Q^2) = \frac{\left( \frac{d\sigma}{dQ^2} \right)_{\nu N}^{\text{NC}} - \left( \frac{d\sigma}{dQ^2} \right)_{\bar{\nu} N}^{\text{NC}}}{\left( \frac{d\sigma}{dQ^2} \right)_{\nu n}^{\text{CC}} - \left( \frac{d\sigma}{dQ^2} \right)_{\bar{\nu} p}^{\text{CC}}} , \quad (11)$$

where  $(d\sigma/dQ^2)_{\nu N}^{\text{NC}}$  and  $(d\sigma/dQ^2)_{\bar{\nu} N}^{\text{NC}}$  are the cross sections of the processes (3) and (4) and  $(d\sigma/dQ^2)_{\nu n}^{\text{CC}}$  and  $(d\sigma/dQ^2)_{\bar{\nu} p}^{\text{CC}}$  are the cross sections of the processes (9) and (10), respectively. Taking into account only the terms which depend linearly on the strange form factors, for the asymmetry we have the following expression:

$$R(Q^2) \mathcal{A}(Q^2) = 1 - \frac{F_A^s(Q^2)}{F_A(Q^2)} - \frac{1}{8|V_{ud}|^2} R(Q^2) \frac{G_M^s(Q^2)}{G_M^3(Q^2)}, \quad (12)$$

where the quantity

$$R(Q^2) = \frac{4|V_{ud}|^2}{1 - 2\sin^2\theta_W \frac{G_M^p(Q^2)}{G_M^3(Q^2)}} \quad (13)$$

is determined by the ratio of the magnetic form factors of the neutron and proton (in Eqs.(12))and.(13)  $\theta_W$  is the Weinberg angle and  $V_{ud}$  is the element of the CKM mixing matrix).

The electromagnetic form factors satisfy the approximate scaling relations

$$\begin{aligned} G_M^p(Q^2) &= \mu_p G_E^p(Q^2), \\ G_M^n(Q^2) &= \mu_n G_E^n(Q^2), \end{aligned} \quad (14)$$

where  $\mu_{p(n)}$  is the total magnetic moment of the proton (neutron) in nuclear Bohr magnetons. In the scaling approximation we have

$$R(Q^2) \mathcal{A}(Q^2) = 1 - \frac{F_A^s(Q^2)}{F_A(Q^2)} - 1.11 \frac{G_M^s(Q^2)}{G_M^3(Q^2)} \quad (15)$$

with a constant  $R(Q^2) = 8.46$ . From Eq.(15) it can be seen that the asymmetry has the same sensitivity to the axial and vector strange form factors.

From Eqs.(12) and (15) it is clear that a measurement of the asymmetry  $\mathcal{A}(Q^2)$  could allow to obtain model independent information about the strange axial and vector form factors of the nucleon. Such information would be of great theoretical interest.

New neutrino experiments (CHORUS[10], NOMAD[11], ICARUS[12], MINOS[13], COSMOS[14], etc.) aimed to search for neutrino oscillations are taking data or are under preparation. We think that now it is a proper time for considering the possibility of using these neutrino facilities in order to get information on the NC neutrino (and antineutrino) elastic scattering on protons.

In Ref.[6] we have discussed in detail the uncertainties connected with our knowledge of the electromagnetic form factors. Nuclear effects will be considered in forthcoming publications.

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